## Title
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ETHAN WELTY/CAVAN IMAGES/ALAMY

A microhydro turbine on the Nam Ou River in Laos generates electricity for nearby villages.

# Deploy diverse renewables to save tropical rivers

A strategic mix of solar, wind and storage technologies around river basins would be safer and cheaper than building large dams, argue **Rafael J. P. Schmitt**, **Noah Kittner** and colleagues.

Demand for clean energy is soaring across developing nations in Africa, South America and southeast Asia. Governments from Myanmar to Brazil face hard decisions. Should they invest billions of dollars in tried-and-tested hydropower, damming yet more rivers to generate electricity? Or should they spend on emerging solar, wind and energy-storage technologies, the costs of which have plummeted in the past decade?

Many emerging economies are planning to increase their hydropower generation. For example, Cambodia is considering spending US$5 billion — almost one-quarter of its gross domestic product — on building the Sambor dam on the Mekong River. Should it go ahead, the dam could generate 11,000 gigawatt hours (GWh) of electricity each year, a big jump from the 7,000 GWh the country generated in 2017.

But a surge of dam development across the tropics threatens to interrupt the planet's last free-flowing rivers[1] — including the Mekong, Congo, Amazon and Irrawaddy. The lives of millions of people and many species depend on these rivers[2]. The projects address important energy needs, but advocates often overestimate economic benefits and underestimate the far-reaching effects on biodiversity and important fisheries. Powerful analytical tools and high-resolution environmental data can clarify trade-offs between engineering and environmental goals, and can enable governments and funding institutions to compare many alternative scenarios for dam building and expansion of renewable energy.

The proposed Sambor dam, for example, would prevent fish from migrating, threatening fisheries worth billions of dollars[3]. It would further cut the supply of sediment to the Mekong Delta (see 'Power decisions'), where some of the region's most fertile farmland is at risk of sinking below sea level by the end of the century. And the dam would do little to bring electricity or jobs to local villagers: much of its hydropower would be exported to big cities in neighbouring nations, far from the rivers that will be affected.

By contrast, spreading a variety of renewable energy sources strategically across river basins could produce power reliably and cheaply while protecting these crucial rivers and their local communities. Solar, wind, microhydro and energy-storage technologies have caught up with large hydropower in price and effectiveness. Hundreds of small generators woven into a 'smart grid' (which automatically responds to changes in supply and demand) can outcompete a big dam.

As the World Hydropower Congress (WHC) meets this week in Paris, we call on decision makers and investors to commit to regional strategies for mixed renewable energy sources.

Comprehensive cost–benefit analyses are needed that consider the impacts and benefits of different forms of energy generation on regional scales. To guide these, researchers need to learn more about how large dams affect river processes, such as fish migration and sediment transport. They should study how to optimize distributed energy systems for improving output, reliability and costs, as well as enhancing local lives and livelihoods, while protecting great rivers and their watersheds. These global opportunities are explored in detail in a report being released at the WHC by the conservation group WWF, the Nature Conservancy and academic collaborators, including two of us (R.J.P.S. and D.M.K.)[4].

## CHANGING ENERGY LANDSCAPE

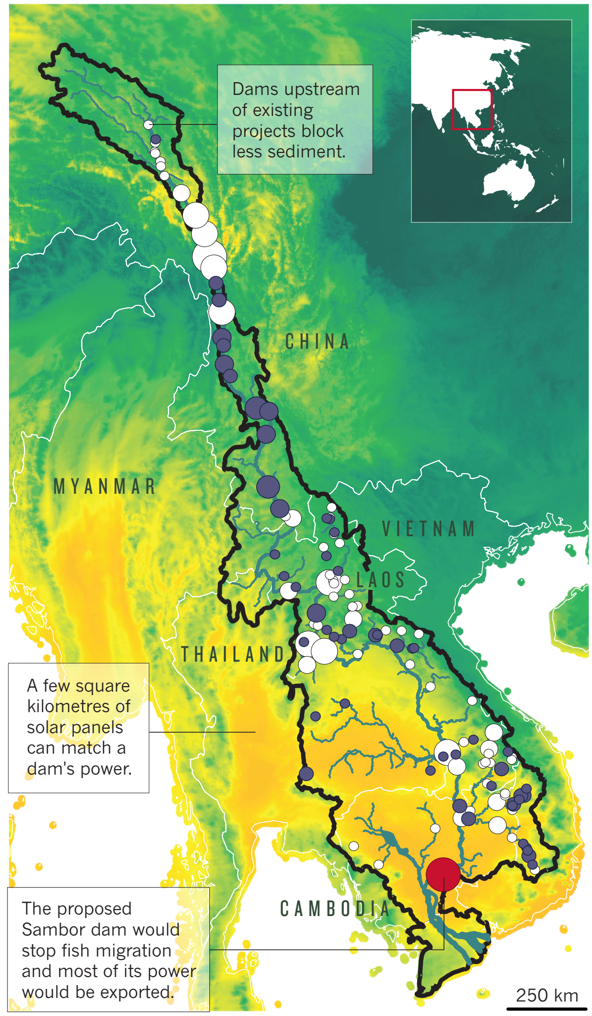
Hydropower has been used for decades to generate renewable electricity on a vast scale. There are more than 60,000 large dams around the world; hundreds more are planned on tropical rivers. Today, hydropower is just one of many options. Covering several square kilometres of land with photovoltaic solar panels or hundreds of wind turbines can produce the same amount of power as a large dam[5,6] at a similar cost. Solar- and wind-energy companies already offer electricity prices of around \$0.05 per kilowatt hour ($kWh^{-1}$). This is as cheap as or cheaper than electricity from hydropower, which costs between \$0.02 and \$0.27 $kWh^{-1}$. The integrated cost of reliable electricity from solar, wind and storage in combined systems could drop below \$0.10 $kWh^{-1}$ (ref. 7), and will keep falling as technology develops.

Hydropower needs to be viewed as part of a broader strategy for clean energy, in which the costs and benefits of different sources should

SOURCES: IRRADIATION MAP: SOLARGIS (2016); DAM DATA: MEKONG RIVER COMMISSION (2014); RIVER NETWORK: R.J.P.S. *ET AL.*; COUNTRY BORDERS: NATURAL EARTH

## POWER DECISIONS

Plans to double the number of large hydropower dams on the Mekong River mean that migrating fish and sediment will be unable to reach the delta. Solar power, as well as wind and other renewables, can complement or replace dams with less impact — if such schemes are well planned.




Mekong basin region
Rivers and tributaries

**Dam sites (megawatts)**

| Built | Potential | |
|---|---|---|
| | | <251 |
| | | 251–1,000 |
| | | 1,001–2,500 |
| | | >2,500 |

**Photovoltaic potential (kilowatt hours per m² per day)**

High 5.73
Low 1.96

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be assessed and weighed against each other.

Large hydroelectric dams can supply a steady stream of 'baseload' electricity, which can be ramped up to meet demand within minutes. Dams can store water (and thus energy) that can be released later. There are no by-products of combustion or hazardous wastes to deal with. They can help with flood protection and water supply.

Dams are cited as a way to meet some of the United Nations' Sustainable Development Goals (SDGs), including affordable and clean energy (SDG 7) and climate action (SDG 13). They can support irrigation for agricultural production (helping to meet SDG 2, zero hunger) and access to clean water (SDG 6). But dams conflict with other objectives, such as maintaining healthy ecosystems in rivers (SDG 6.6), food security in fisheries (SDG 2) and the resilience of cities (SDG 11) on coastal plains and deltas.

The impacts of dams accumulate across a river basin. Yet most hydropower projects are planned in isolation. As more streams are dammed, less sediment reaches the coast and river channels and banks erode. Lower river levels allow salt water to intrude into coastal aquifers, diminishing supplies of fresh water. Human health can be affected. For example, across Africa, incidences of the parasitic disease schistosomiasis are rising as dams interrupt the migration of prawns that feed on the parasite's host, water snails[8].

Dams lock in costs and consequences for decades[9]. Private investors profit most from long-term agreements to purchase power. And investments are risky: local protests can stall construction, adding to costs. For example, in Myanmar in 2011, villagers' concerns over the environmental impacts of the 3,600-megawatt (MW) Myitsone dam halted its construction on the upper Irrawaddy River, after developers had already invested hundreds of millions of dollars.

The energy that dams produce is not assured in a changing climate, in which river flows and hydrological cycles will shift[10]. Dams are already unable to meet demand during major droughts, such as the record-breaking dry spell that hit the Mekong basin in 2016. Hydropower output and revenues fell, hitting local economies hard. Cambodia is currently plagued by blackouts because of low river flows and reduced water levels in reservoirs.

A portfolio of wind, solar and hydropower would be less vulnerable to changes in regional hydrology. Solar panels and wind turbines are modular and swift to install or update. Constructing many small projects avoids saddling developing countries with billions of dollars of debt. They can be planned and financed more flexibly than large hydropower projects. By feeding power into a smart grid, consumers tap the cheapest energy and suppliers balance generation, storage and demand in real time.

For example, mixed systems of renewable energy and microgrids are being piloted in Thailand, on islands and in remote mountainous regions that are hard to reach with conventional transmission lines[11]. Lingering problems with intermittency and imbalances in supply and demand, such as during hot periods, can be solved with smart grids and battery storage. These approaches are helping to minimize blackouts and reduce the reliance on back-up diesel generators in northern Thailand's mountainous Mae Hong Son province, for instance.

Challenges remain. Power from large solar and wind projects cannot benefit local communities if it is exported. It is expensive to install renewables in remote areas. Storage must become cheaper and more effective: flow batteries, flywheels, supercapacitors and retrofitting of pumped storage in existing reservoirs all need further study. The collective impacts of many microhydro dams in a region also need to be assessed.

## STRATEGIC PLANNING

Renewable-energy strategies and hydropower expansion must be planned on basin or regional scales to find good trade-offs between impact and benefits[4]. On the major tributaries of the lower Mekong, for example, dams have been built ad hoc. Existing ones exploit only 50% of the tributaries' potential hydropower yet prevent 90% of their sand load from reaching the delta[12]. There was a better alternative: placing more small dams higher up the rivers could have released 70% of the power while trapping only 20% of the sand[12].

Similarly, strategic planning is crucial when choosing sites for solar and wind farms. Emerging economies are beginning to build them at utility scales. For example, Cambodia began operating its first large solar-power project with a capacity of 10 MW in Bavet City in October 2017, and Thailand is investing $1.5 billion in a 600-MW wind farm in Laos. But again, these projects should not be built in isolation.

Impacts of these projects on the landscape need to be considered, too. Solar and wind farms might be built on patches of land that have low conservation value, such as along roads, or even floating on hydropower reservoirs[4]. Thai investors plan to install up to 45 MW of floating photovoltaics at Sirindhorn dam in eastern Thailand, for example. Solar panels and small wind turbines can be put on or near buildings to minimize infrastructure and reduce energy losses in transmission.

Analyses of energy strategies should follow three steps. First, policymakers and researchers need to explore a wide range of mixed energy systems (including hydropower and measures to reduce demand and increase energy efficiency) to find the best combination that minimizes generation costs and optimizes base and peak loads. Second, assess which combination of dam sites has the least impact, if hydropower is required. Third, evaluate the impacts and trade-offs of the most favourable energy systems on aquatic and terrestrial ecosystems across the basin, aiming to retain free-flowing river courses, agricultural land and tropical forest. All groups affected by energy generation must be involved.

Two main hurdles must also be overcome. The first is a lack of data on river processes, such as fish migration. The second is politics. Large river basins such as the Mekong span many countries and each wants to generate power within its borders, irrespective of impacts downstream. There are vested interests in protecting traditional food systems, procuring electricity revenues and securing water resources. Regional cooperation across basins is therefore crucial.

> ***"Constructing many small projects avoids saddling developing countries with billions of dollars of debt."***

How would these decisions work in practice? For the lower Mekong basin, countries such as Cambodia must choose whether to build potentially damaging dams — such as the Sambor dam — or to invest more money in solar and wind farms. Hydropower could instead be imported from less damaging sites upstream in China[4].

## POLICY DIRECTIONS

The following steps would extend strategic planning to renewable energy 'powersheds'.

First, improve governance over the river basin, from local to regional scales. Transnational management organizations focused on particular basins should be set up, and the roles of existing ones such as the Mekong River Commission strengthened. These bodies might be coordinated by the UN. Local voices should be heard when planning clean-energy policies in developing nations. Encouragingly, some policymakers are listening. For example, the Malaysian Federal Minster of Works, Baru Bian, said in March that "any so-called clean energy policy that destroys primary forests is not clean. Neither are energy policies that displace Indigenous communities"[13].

River-basin organizations and governments must take a holistic perspective on energy planning, including consideration of non-hydropower renewables, energy efficiency, demand-side management and risks from future climate change. Banks and financiers that drive investment in clean energy should spearhead strategic assessments. Legal approaches can be powerful, too. In 2017, the Whanganui River in New Zealand was recognized by the government as a legal 'person', enshrining rights to the connected functioning of its watershed and Indigenous people's links to the river.

Researchers need to fill data gaps across whole river basins, from fish migration and sediment transport to community empowerment and impacts on food systems. Such an assessment has been done for the Irrawaddy, and similar efforts are under way in Nepal. The costs of lost ecosystem services over the life cycle of energy projects must be included in cost–benefit analyses. Such research is cheap compared with the costs of building dams and mitigating environmental impacts.

Basin-wide planning can create an energy future in which both people and rivers thrive. ■

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